An erotetic approach to explanation by specification

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ABSTRACT. In earlier publications of the first author it was shown that intentional explanation of actions, functional explanation of biological traits and causal explanation of abnormal events share a common structure. They are called explanation by specification (of a goal, a biological function, an abnormal causal factor, respectively) as opposed to explanation by subsumption under a law. Explanation by specification is guided by a schematic train of thought, of which the argumentative steps not concerning questions were already shown to be logically valid (elementary) arguments.

Independently, the second author developed a new, inferential approach to erotetic logic, the logic of questions. In this approach arguments resulting in questions, with declarative sentences and/or other questions as premises, are analyzed, and validity of such arguments is defined.

In the present paper it is shown that all four kinds of erotetic argumentative steps occurring in the train of thought of explanation by specification are valid arguments in the sense of inferential erotetic logic. Hence, in view of the fact that the other argumentative steps were already shown to be valid, it may be concluded that the logical structure of explanation by specification can be as well-established as that of explanation by nomological subsumption. Moreover, explanation by specification provides some illustrations of the applicability of erotetic logic in everyday life and some empirical sciences.

1. INTRODUCTION

The idea that not all decent forms of explanation have to be nomological explanations, i.e. explanations by subsumption under a law, is well known. In particular, intentional explanation of actions, functional explanation of biological traits and even certain kinds of causal explanation have frequently been proposed as autonomous types of explanation.

The first author of the present paper has argued in a series of consecutive publications (Kuipers, 1985, 1986a, 1986b, and to appear) that the three mentioned types of non-nomological explanation have a common structure. In all these cases there can be distinguished several ingredients of a similar type. The main ones are two meaning postulates, a methodological principle, and a standard train of thought underlying the search for the relevant explanation. The crucial differences lie in the meaning components of the so-called *key meaning postulate*: these components are distinct for a specific intentional, functional and causal

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statement, respectively, and they are typical for the particular subject matter. However, the common structure is similar in all the three cases and centers around the specification of a particular goal, function, and causal factor, respectively. This provides more than enough reason to speak of one general type of explanation, i.e. explanation by specification, with at least three particular subtypes, viz. explanation by intentional, functional and causal explanation, respectively.

The second author developed completely independently in a sequence of publications (Wiśniewski, 1985, 1989, 1990a, 1990b, 1991a, 1991b, and 1994) a new approach to erotetic logic, i.e. the logic of questions. It may be called the *inferential approach*: it aims at accommodating the logic of questions to the old idea that logic is the science of argument. This was done by developing a logical theory of *erotetic arguments* (e-arguments for short). These arguments are counterparts to *erotetic inferences*, that is, thought processes in which we arrive at a question on the basis of some previously accepted declarative sentence or sentences and/or a previously posed question. There are, then, two kinds of e-arguments, and both types suggest very plausible semantic conditions for validity. In the case of an e-argument of the first kind the premises are declarative and the conclusion is a question. In the case of an e-argument of the second kind one premise and the conclusion are questions, and there may or may not be some declarative premises involved. The general idea behind the validity definitions is that an e-argument is valid when the question being the conclusion *arises* from the premises; in the case of e-arguments arising seems to play the same role as entailment in the case of arguments understood in the standard way. Yet, since we have two kinds of e-arguments, two different logical relations are relevant here; they may be referred to (in a little awkward manner) as the arising of a question from a set of declarative sentences and the arising of a question from a question and possibly a set of declarative sentences, respectively. The definition of the semantic concept of *generation of a question by a set of declarative formulas* (cf. Wiśniewski, 1989, or 1991a) is an explication of the first of the above concepts, whereas the definition of the semantic concept of *implication of a question by a question and a set of declarative formulas* (cf. Wiśniewski, 1990a, or 1994) is an explication of the second. By means of the erotetic concepts of generation and implication we can distinguish two types of e-arguments: *question generating arguments* and *question implying arguments*. Both may be regarded as *valid erotetic arguments*.

The first author already used to stress that several steps in the train of thought in searching an explanation by specification were standard deductively valid arguments. This justified the intuitive feeling of many people that such (intentional, functional and causal) explanations, though no valid deductive-nomological arguments, nevertheless involve some valid arguments of other kinds. Yet, there are also some other steps in the train of thought in question. These steps can be distinguished into two kinds. The one kind concerns the introduction of new information. Hence such a step is not an argument with premises and a conclusion, it is a non-argumentative step. The other kind of remaining steps concerns the arriving at and then posing of a question. For the second author it was almost immediately clear that these steps involving questions could not only be interpreted as erotetic arguments, but that they were valid erotetic arguments. As a matter of fact, they are either question generating arguments or question implying arguments. Hence, *all argumentative steps in the train of thought are valid arguments, either standard or erotetic.*

The claimed merits of this paper are two-fold. On the one hand it shows that the logical structure of explanation by specification is as well-established as in the case of explanation by nomological subsumption. On the other hand it provides some illustrations of the applicability of erotetic logic in everyday life and some empirical sciences.

2. THE STRUCTURE OF EXPLANATION BY SPECIFICATION

Let us start with a typical example of each of the three kinds of explanation we are interested in.

> Henry VIII divorced with the intention to remarry and obtain a male heir.
>
> The biological function of the systematic fanning movement of sticklebacks is to supply the eggs with oxygen.
>
> The catastrophe with the Challenger was caused by a leaking gasket.

We conceive such explanations as *specifications* of the following *unspecific statements*:

Henry VIII divorced intentionally.
The systematic fanning movement of sticklebacks is functional.
The catastrophe with the Challenger had a specific cause.

Those unspecific statements are attached to some *factual statements*; in the present case they are:

Henry VIII divorced.
Sticklebacks show systematic fanning movement.
There occurred a catastrophe to the Challenger.

The three types of statements will play a crucial role in our analysis. We will therefore introduce the following abbreviations for them:

$\mathbf{F}(\alpha, \beta)$ *factual statement*
person α performed action β
organisms of type α have trait β
abnormal event β occurred to system α

$\mathbf{U}(\alpha, \beta)$ *unspecific statement*
person α performed action β intentionally
trait β of organism of type α is functional
abnormal event β occurred to system α due to some abnormal causal factor

$\mathbf{S}(\alpha, \beta, \gamma)$ *specification of the unspecific statement*
person α performed action β with the intention of approaching γ
the biological function of trait β of organisms of type α is γ
abnormal event β occurred to system α due to γ

The letter γ refers to a description of a goal, description of a biological function, and a description of a causal factor, respectively; the term "description" is used here in its non-technical sense, as referring to any phrase which can perform the function of a name in the above expressions.

In what follows we will be using the expression *specific statement* instead of the long expression *specification of the unspecific statement*.

For some technical reasons we will also introduce two auxiliary technical concepts. First, we introduce the following:

$C(x)$ *category condition*
x is a goal
x is a biological function
x is a causal factor

With each category condition $C(x)$ we will accompany the *nominal category determined by it*, in symbols $[C(x)]$.[1] The nominal category determined by a category condition $C(x)$ consists of all the expressions which can perform the function of a name of an object having the property C; in the three cases mentioned above the corresponding nominal categories consist of expressions performing the functions of names of goals, names of biological functions, and names of causal factors, respectively. We assume that the nominal categories determined by the analyzed category conditions are at least two-element: there are always at least two conceptual possibilities.

The further explication consists of two stages. In the first stage a meaning analysis is given for the relevant specific statements. In the second stage the thought process of the researcher is reconstructed.

3. MEANING ANALYSIS

The general idea now is, first, that each specific statement, $S(\alpha, \beta, \gamma)$, can be decomposed into some meaning components; some of them are trivial, but some are not. Second, an unspecific statement, $U(\alpha, \beta)$, may be construed as a kind of existential generalization of the (any of) corresponding specific statement. Formally, we postulate the following two (schemes for) meaning postulates:

MP-1: $S(\alpha, \beta, x) \equiv F(\alpha, \beta) \; \& \; C_1(x) \; \& \ldots \& \; C_n(x)$

MP-2: $U(\alpha, \beta) \equiv \exists x (C(x) \; \& \; S(\alpha, \beta, x))$

where the expressions $C_1(x), \ldots, C_n(x)$ contain int. al. either both α and β or only one of them; x is here the only free variable. We will call the last component $C_n(x)$ the *causal effectiveness component* (see below). $F(\alpha, \beta)$ is of course a (standard) trivial meaning component. The remaining meaning components have to be specified in different ways for each particular kind of explanation we are interested in. The specification of the meaning components provides the so-called *key* to the explanation in question.

The meaning analysis for keys for specific intentional, functional and causal statements have been proposed in the previous publications of the first author (cf. Kuipers, 1985, 1986a, 1986b, and to appear). Without going into details we therefore only sketch here the non-trivial meaning components[2] of the specific statements in question.

Non-trivial meaning components of the *specific intentional statement*:

(a) person α performed action β with the intention of approaching γ

(a_1) α desired γ,
(a_2) α believed β to be useful to approach γ,
(a_3) both α's desiring of γ and α's belief that β was useful in approaching γ were causally effective for α's performance of β.

Non-trivial meaning components of the *specific functional statement*:

(b) the biological function of trait β of organisms of type α is γ

(b_1) β of α is a positive causal factor for γ,
(b_2) γ is a positive causal factor for the reproduction and survival of α,
(b_3) both β and γ were causally, i.e. evolutionary, effective for α having β.

Non-trivial meaning components of the *specific causal statement*:

(c) event β occurred to system α due to γ

(c_1) γ occurred to α as an abnormal causal factor,
(c_2) there were normal causal factors occurring to α such that these together with γ caused the occurence of β to α,
(c_3) γ was causally effective in the causation of the occurrence of β to α along the suggested causal line.

The conditions (a_3), (b_3) and (c_3) are the causal effectiveness components or CE-components for short. The inclusion of the CE-components in the train of thought is defended extensively in Kuipers (in preparation); they have not been formally included in the previous presentations. One additional remark is also in order here. Although in each of the above cases we distinguished three particular non-trivial meaning components, one may argue that some deeper or even different analysis is also possible. Moreover, it is also possible that some other kinds of explanation are explanation by specification. For these reasons we formulated the meaning postulates in schematic form and left room for any number of non-trivial meaning components. Such a reformulation, however, does not affect in a substantial way the scheme of the train of thought we are going to propose.

4. THE TRAIN OF THOUGHT IN SEARCHING AN EXPLANATION BY SPECIFICATION

First, we need a number of preparatory steps.

(A) The word "explanation" may refer either to a process or to a result of this process; the result is usually described as a justified answer to the relevant explanation-seeking question. In the case of explanation by specification these answers are simply the specific statements of the form $S(\alpha, \beta, \gamma)$. Let us observe that sentences of this kind analyzed above may be regarded as *direct answers* (i.e. possible and just-sufficient answers) to the following questions:

(i) What was the intended goal of person α with his/her performance of action β?

(ii) What is the biological function of trait β of organisms of type α?

(iii) What was the cause of abnormal event β that occurred to system α?

The above questions may be regarded as having the logical form:

(iv) Which x, being a $\mathbf{C}$, is such that $S(\alpha, \beta, x)$?

where $\mathbf{C}$ is the predicate that occurs in the relevant category condition (note that x is a variable here – a *queriable*, so to say – but α and β are constants); the *direct answers* to (iv) are of the form $S(\alpha, \beta, \gamma)$, where γ is an element of $[\mathbf{C}(x)]$.

Let us notice that (iv) is a which-question. On the other hand, why-questions are usually regarded as paradigmatic examples of explanation-seeking questions. Yet, there are strong arguments for the claim that there are questions of other kinds that can be used to ask for explanation (cf. Bromberger, 1992). In the case of explanation by specification what-questions that are essentially which-questions express the explanation-seeking questions. On the other hand, each direct answer to a question of the form (iv) may be regarded either as an answer to the corresponding question of the form "Why $\mathbf{F}(\alpha, \beta)$?" or as a sentence which entails such an answer. So explanations by specification may be regarded as constituting items of *explanatory knowledge* as well.

(B) Before we present the train of thought, that is, before we present (our idealized scheme of) the *process* of explanation by specification, we need to introduce some notation for the questions which will occur in our presentation. First, following Belnap (cf. Belnap and Steel, 1976) we will formalize questions of the form (iv) as:

(v) $\quad ?^1(\mathbf{C}(x)/\mathbf{S}(\alpha, \beta, x))$.

Of course, by a direct answer (that is, a possible and just-sufficient answer) to a question of the form (v) we still mean a sentence of the form $\mathbf{S}(\alpha, \beta, \gamma)$, where γ is an element of $[\mathbf{C}(x)]$, i.e. is (depending on the interpretation of $\mathbf{C}$) an expression performing the function of a name of a goal, of a biological function, and of a causal factor, respectively.

Questions of the form (v) fit the more general scheme:

(*) $\quad ?^1(\mathbf{C}(x)/A(x))$

where $A(x)$ is a sentential function with x as the only free variable. Direct answers to a question of the form (*) are the sentences of the form $A(\gamma)$, where γ is an element of $[\mathbf{C}(x)]$, that is, of the nominal category determined by the category condition $\mathbf{C}(x)$. The numeral "1" indicates that (*) is the so-called single-example which-question, i.e. calls for an answer of the form $A(\gamma)$, not for a conjunction of such sentences.[3]

Second, we will use the following notation for whether-questions which will occur in our presentation (this is not a notation, however, which is applicable for all whether questions; for such a notation see e.g. Belnap and Steel, 1976, or Kubiński, 1980). An expression of the form:

(**) $\quad ?(A_1, \ldots, A_n \mid \neg A_1, \ldots, \neg A_n)$

where $n \geq 1$ and $A_1, \ldots, A_n$ are syntactically different sentences (closed formulas) refers to a question whose direct answers are of the form

(vi) $B_1 \& \ldots \& B_n$

where B_i – for $1 \leqslant i \leqslant n$ – is either of the form A_i or of the form $\neg A_i$.

Some examples may make this notational convention clear. If a question Q is of the form:

(a) $?(A \mid \neg A)$

then the direct answers to Q are the sentences A and $\neg A$, exclusively; Q is thus a simple yes-or-no question. If, however, Q is of the form

(b) $?(A_1, A_2 \mid \neg A_1, \neg A_2)$

then the set of direct answers to Q is:

(c) $\{A_1 \& A_2, A_1 \& \neg A_2, \neg A_1 \& A_2, \neg A_1 \& \neg A_2\}$

that is, Q is the so-called two-component conjunctive question.

(C) In order to go on we also have to introduce some crucial principles, which are peculiar for each analyzed kind of explanation. To be more precise, we need the heuristic-methodological:

HM-principle: if $\mathbf{F}(\alpha, \beta)$ then $\mathbf{U}(\alpha, \beta)$
actions are performed intentionally
biological traits are functional
abnormal events have specific causes

A HM-principle is not a law-claim. Exceptions are not excluded. It functions as a search principle. More specifically, it functions as a default rule: it is the starting point as long as there are no good reasons to assume the contrary.

(D) In what follows the presentation of the train of thought deviates somewhat from those published earlier. First, the CE-component has been added. Second, the order of some steps was changed, but also in the present presentation the deductive transitions are valid. Third, some steps have been split in order to make explicit some hidden standard deductive structure. Of course, all changes, except the first one, were made in view of the erotetic analysis. However, these changes do not mean any essential deviation from the original presentations.

In order to make reading easier we illustrate each step by one particular example, viz. the systematic fanning movement of the sticklebacks. For this purpose we introduce the abbreviations:

sfm: systematic fanning movement
r&s: reproduction and survival
seo: supplying eggs with oxygen

We will also make some comments; they do not belong to the schema itself and will be inserted in brackets [ ]. The concept of acceptance is used below rather loosely; in particular, we do not assume that sentences once accepted are irrevocable.

STEP 0: We *accept* the meaning postulates MP-1 and MP-2.

STEP 1: We *accept* the factual statement:

(1) $F(\alpha, \beta)$
Sticklebacks show *sfm*.

[The sentence (1) is accepted as a confirmed hypothesis].

STEP 2: We *accept* the following instance of the HM-principle:

(2) $F(\alpha, \beta) \rightarrow U(\alpha, \beta)$
If sticklebacks show *sfm*, then *sfm* of stickleebacks is functional.

[The sentence (2) is accepted as a hypothesis to be tested.]

STEP 3: From (1) and (2) we *derive* the sentence:

(3) $U(\alpha, \beta)$
sfm of sticklebacks is functional.

and then we *accept* it.

[Since (2) was only hypothetically assumed, (3) is a hypothesis to be tested as well. The same holds true for all further conclusions which rest upon (2).]

STEP 4: We *derive* from (3) and the meaning postulate MP-2 the sentence:

(4) $\exists x(C(x) \mathbin{\&} S(\alpha, \beta, x))$
There is some biological function of *sfm* of sticklebacks

and then we *accept* it.

STEP 5: From (4) we *pass* to the question:

(5) $?^1(C(x)/S(\alpha, \beta, x))$
What is the biological function of *sfm* of sticklebacks?

and then we *pose* it.

[The question (5) is our main explanation-seeking question. Now we start the process of looking for a justified answer to it.]

STEP 6: We *derive* from the meaning postulate MP-1 its universal generalization (with respect to x) G(MP-1); then we derive from G(MP-1) and the sentence (4) the sentence of the form:

(6) $\exists x(\mathrm{C}(x)\ \&\ C_1(x)\ \&\ \ldots\ \&\ C_n(x))$
There is a biological function x such that *sfm* of sticklebacks is a positive causal factor for x and x is a positive causal factor for *r&s* of sticklebacks showing *sfm* and both *sfm* and x were causally, i.e. evolutionary, effective for sticklebacks.

STEP 7: We *pass* from the question (5) on the basis of the meaning postulate MP-1 together with the sentence (1) to the question:

(7) $?^1(\mathrm{C}(x)/C_1(x)\ \&\ \ldots\ \&\ C_n(x))$
Which biological function x is such that *sfm* of sticklebacks is a positive causal factor for x and x is a positive causal factor for *r&s* of sticklebacks showing *sfm* and both *sfm* and x were causally, i.e. evolutionary, effective for sticklebacks?

and then we *pose* it.

STEP 8: We *accept* some sentence of the form:

(8) $\mathrm{C}(\gamma)$
seo (supplying eggs with oxygen) is a biological function.

where γ belongs to the nominal category determined by $\mathrm{C}(x)$ (e.g. is a description of a goal or of a biological function or of a causal factor).

[The sentence (8) is accepted as a confirmed hypothesis. In practice γ refers to a possibility that comes to the mind of the researcher at a given moment; it may happen for many reasons. Of course γ will be not trivial, e.g. not referring to the internal goal of action β, not referring to trait β, not referring to event β.]

STEP 9: We *pass* from the question (7) on the basis of the sentences (6) and (8) to the question:

(9) $?(C_1(\gamma), \ldots, C_n(\gamma) | \neg C_1(\gamma), \ldots, \neg C_n(\gamma))$
Is *seo* such that *sfm* of sticklebacks is a positive causal factor for *seo* and *seo* is a positive causal factor for *r&s* of sticklebacks showing *sfm* and both *sfm* and *seo* were causally, i.e. evolutionary, effective for sticklebacks?

and then we *pose* it.

STEP 10: We *pass* from the question (9) to the following questions:

(10.1) $?(C_1(\gamma) \mid \neg C_1(\gamma))$
(10.2) $?(C_2(\gamma) \mid \neg C_2(\gamma))$

....

(10.n) $?(C_n(\gamma) \mid \neg C_n(\gamma))$
Is it the case that *sfm* of sticklebacks is a positive causal factor for *seo*?
Is it the case that *seo* is a positive causal factor for *r&s* of sticklebacks showing *sfm*?
Is it the case that both *sfm* and *seo* were causally, i.e. evolutionary, effective for sticklebacks?

and then we *pose* them.

STEP 11. We attempt to *solve* the problems expressed by the questions (10.1)–(10.n); that is, we try to justify some direct answer to each of these questions.

The further train of thought depends on the results obtained in Step 11.

Assume that we succeeded in justifying the *affirmative* direct answers to all the questions (10.1)–(10.n).[4] [This actually happened in the sticklebacks example.] Then we go to:

STEP 12a: We *accept* the following sentences:

(12.a.1) $C_1(\gamma)$
(12.a.2) $C_2(\gamma)$

....

(12.a.n) $C_n(\gamma)$
sfm of sticklebacks is a positive causal factor for *seo*.
seo is a positive causal factor for *r&s* of sticklebacks showing *sfm*.
both *sfm* and *seo* were causally, i.e. evolutionary effective for sticklebacks.

[Since the above sentences were justified in Step 11, they are now accepted as confirmed hypotheses].

STEP 13a: We *derive* from the sentences (12.a.1)–(12.a.n) together with the sentence (1) and the meaning postulate MP-1 the sentence:

(13.a) $S(\alpha, \beta, \gamma)$
The biological function of *sfm* of sticklebacks is *seo*.

and then we *accept* it.

[Note that since all the non-analytical premises involved in this step are confirmed hypotheses, the sentence (13.a) is a confirmed hypothesis as well. On the other hand, (13.a) is a direct answer to our explanation-seeking question. *We therefore have a conclusion which is both justified and is an explanation by specification*.]

STEP 14a: We *derive* from the sentence (13.a), the sentence (8) and the meaning postulate MP-2 the sentences:

(3) $U(\alpha, \beta)$
(2) $F(\alpha, \beta) \rightarrow U(\alpha, \beta)$

and then we *accept* them.

[The sentences (3) and (2) were accepted in Steps 3 and 2 as hypotheses to be tested. Now they are confirmed hypotheses.]

Assume that we have justified some *negative* direct answer to some of the questions (10.a.1) – (10.a.n) or that no clear results are obtained in case of at least one of those questions. Then we go to:

STEP 12b: We *accept* some sentence of the form:

(12.b)) $C(\gamma_1)$

where γ_1 also belongs to the nominal category determined by $C(x)$ (e.g. is a description of a goal or of a biological function or of a causal factor), but is *different from* the previously tested γ.

[The sentence (12.b) is also accepted as a confirmed hypothesis.]

STEP 13b: Like in Step 9, but with regard to γ_1 instead of γ and the sentence (12.b) instead of the sentence (8).

STEP 14b: Like in Step 10, but with regard do γ_1.

STEP 15b: Like in Step 11, but with regard to γ_1.

The further train of thought depends on the results obtained in Step 15b. If we succeeded in justifying the *affirmative* direct answers to the yes-or-no questions that occur in Step 14b, we then proceed in the way analogous to that of Steps 13a and 14a, but with regard to γ_1 (and with the sentence (12b) instead of (8)). If, however, we have justified some *negative* direct answer to some of the relevant yes-or-no questions or no clear results are obtained, we then repeat the procedure with respect to some γ_2 which is different from both γ and γ_1.

The process goes on until some sentence of the form $S(\alpha, \beta, \gamma_i)$, *where* $\gamma_i \in [C(x)]$ – *that is, an explanation by specification – becomes available as the conclusion of the results of the preceding steps.* If this is so, then we proceed in a way analogous to that of Steps 13a and 14a, but with respect to γ_i (and of course $\mathbf{C}(\gamma_i)$). Yet, it may happen that we will not succeed even in a long sequence of consecutive rounds. In this case we usually conclude, for the time being – by Inductive Generalization – that it is not the case that $\mathbf{U}(\alpha, \beta)$.

(E) Let us add that the process of explanation by specification may have several rounds even if we were successful with respect to some goal/biological function/causal factor. The reason is that we usually suspect that a given action might aim at some simultaneous goals, that a given biological trait may have several biological functions, and that an abnormal event might occur due to several specific causes. Yet, looking for further specifications of the unspecific statements is essentially looking for further specific statements of the form $S(\alpha, \beta, \gamma_j)$; in doing this we can proceed along the lines described above. To be more precise, we start the round by the acceptance of some new confirmed sentence of the form $C(\gamma_k)$, where γ_k belongs to the relevant nominal category but is also a description of some simultaneous goal/biological function/causal factor; then we proceed in the way analogous to that which begins at Step 9 of the above schema (but with omitting the analogue of Step 14a if we were successful). So the argumentative steps involved in each round are of the same formal structure.

Finally, let us stress that after a more or less exhaustive investigation of simultaneous goals/biological functions/abnormal causal factors we may start the investigations of the possible prospective goals related to those just found, of the biological traits or functions which are functional with regard to those just found, or of the specific cause(s) of the just found abnormal causal factors. This, however, may be done in an analogous way: the formal structure of the relevant argumentative steps is the same.

5. THE LOGIC OF ARGUMENTATIVE STEPS

The argumentative steps of the train of thought presented above are either standard (both premises and conclusion are declarative) or erotetic (the conclusion is a question, whereas the premises are declaratives, or declaratives and a question, or only a question). It is clear that all the standard argumentative steps are valid arguments; valid both syntactically (they apply such deductive rules as Modus Ponens, Existential Generalization,[5] Universal Generalization, Replacement by an Equivalent, Conjunction Introduction, etc.) and semantically (the conclusions are entailed by the premises). But what about the erotetic argumentative steps? It is easily seen that the train of thought presented above involves argumentative erotetic steps having the following forms:

$$\frac{\exists x(\mathbf{C}(x) \mathbin{\&} \mathbf{S}(\alpha, \beta, x))}{?^1(\mathbf{C}(x)/\mathbf{S}(\alpha, \beta, x))} \tag{1}$$

$$\frac{\begin{array}{l} ?^1(\mathbf{C}(x)/\mathbf{S}(\alpha, \beta, x)) \\ \mathbf{S}(\alpha, \beta, x) \equiv \mathbf{F}(\alpha, \beta) \mathbin{\&} C_1(x) \mathbin{\&} \ldots \mathbin{\&} C_n(x) \\ \mathbf{F}(\alpha, \beta) \end{array}}{?^1(\mathbf{C}(x)/C_1(x) \mathbin{\&} \ldots \mathbin{\&} C_n(x))} \tag{2}$$

$$\frac{\begin{array}{l} ?^1(\mathbf{C}(x)/C_1(x) \mathbin{\&} \ldots \mathbin{\&} C_n(x)) \\ \exists x(\mathbf{C}(x) \mathbin{\&} C_1(x) \mathbin{\&} \ldots \mathbin{\&} C_n(x)) \\ \mathbf{C}(\gamma_i) \end{array}}{?(\mathrm{C}_1(\gamma_i), \ldots, \mathrm{C}_n(\gamma_i) \mid \neg \mathrm{C}_1(\gamma_1), \ldots, \neg \mathrm{C}_n(\gamma_i))} \tag{3}$$

where γ_i is an element of $[\mathbf{C}(x)]$,

$$\frac{?(C_1(\gamma_i), \ldots, C_n(\gamma_i) \mid \neg C_1(\gamma_i), \ldots, \neg C_n(\gamma_i))}{?(C_k(\gamma_i) \mid \neg C_k(\gamma_i))} \tag{4}$$

where $1 \leqslant k \leqslant n$.

An e-argument of the form (1) occurs in Step 5, whereas an e-argument of the form (2) occurs in Step 7. E-arguments of the forms (3) and (4) occur, in turn, in Steps 9 and 10, respectively (and also in the corresponding steps of further rounds, if there are any).

But does that mean that each erotetic argumentative step involved in the train of thought described above is a *valid* erotetic argument? In order to answer this question we need a bit of erotetic logic.

(A) There are two kinds of erotetic arguments. An *e-argument of the first kind* may be regarded as an ordered pair $\langle X, Q \rangle$, where X is a non-empty and finite set of declarative formulas and Q is a question. Similarly, an *e-argument of the second kind* is an ordered triple $\langle Q, X, Q^* \rangle$, where Q and Q^* are questions and X is a finite set of declarative formulas. X may be empty; if X is empty, then the corresponding e-argument is called *pure erotetic argument*. For example, (1) is an e-argument of the first kind, whereas arguments of the form (2), (3) and (4) are examples of e-arguments of the second kind; each e-argument of the form (4) is of course even a pure erotetic argument.

The general idea behind the validity definitions is that an e-argument is valid when the question being the conclusion *arises* from the premises; in the case of e-arguments arising seems to play the same role as entailment in the case of arguments understood in the standard way. Yet, since we have two kinds of e-arguments, two notions of the arising of a question are relevant here: the arising of a question from a set of declaratives and the arising of a question from a question and a (possibly empty) set of declaratives. These concepts do not coincide. On the other hand, there are serious reasons for which both of them can be explicated in semantic terms. The definition of the semantic concept of *generation of a question by a set of declarative formulas* (cf. Wiśniewski, 1989, or 1991a) is an explication of the first concept of arising, whereas the definition of the semantic concept of *implication of a question by a question and a set of declarative formulas* (cf. Wiśniewski, 1990a, or 1994) is an explication of the second. By means of the erotetic concepts of generation and implication we can then define the semantic concepts of *question generating argument* and *question implying argument*. Since the concepts of generation and erotetic implication are explications of the intuitive concepts of the arising of a question, both question generating arguments and question implying arguments may be regarded as *valid erotetic arguments*.

In order to go on we need the definitions of the erotetic concepts of generation and implication. This, however, requires some preparatory steps.

(B) Let $\mathscr{L}$ be a first-order language enriched with expressions which enable us to form questions. We assume that to each question of $\mathscr{L}$ there is assigned an at least two-element set of *direct answers*, which are sentences (declarative formulas without free variables) of $\mathscr{L}$ and which are regarded – looking from the pragmatic point of view – to be the possible and just-sufficient answers to the question. Yet, we assume that direct answers are defined in purely syntactical terms (see e.g. Belnap and Steel, 1976, or Kubiński, 1980, for this kind of approach). So it is not the case that a necessary condition of being a direct answer is to be known to the questioner – or to be in his/her mind – when he/she asks the question.

Let us assume that the declarative part of $\mathscr{L}$ is supplemented with a standard model-theoretical semantics. An *interpretation* of $\mathscr{L}$ is an ordered pair $\langle M, f \rangle$, where M is a non-empty set (*the universe*) and f is an *interpretation function* of the usual extensional kind (defined on the set of non-logical and "non-erotetic" constants of $\mathscr{L}$). The concepts of *satisfaction* and *truth in an interpretation* are defined for declarative formulas (d-wffs for short) in the standard way. We do not assign truth and falsity to questions. Yet, we shall introduce the concept of soundness of a question in a given interpretation of the language.[6] We say that a question Q of $\mathscr{L}$ is *sound in an interpretation* $\mathfrak{M}$ of $\mathscr{L}$ iff at least one direct answer to Q is true in $\mathfrak{M}$. Thus, roughly, a sound question is a truly answerable question; of course this concept is relativized to an interpretation of the language (a question can be sound in one interpretation without being sound in some other(s) interpretation(s)). A question which is sound in each normal interpretation of the language is said to be *safe*; otherwise a question is said to be *risky*.

We assume that the class of interpretations of $\mathscr{L}$ includes a non-empty subclass (not necessarily a proper subclass) of *normal interpretations*; the reason for this step is that we want to have the possibility of reflecting some peculiarities of a natural language, connected mainly with different analytical (but not logical) implicatures in it.[7] We say that a set of d-wffs X of $\mathscr{L}$ *entails* a d-wff A of $\mathscr{L}$ iff A is true in each normal interpretation of $\mathscr{L}$ in which all the d-wffs in X are true. We also need some generalization of the concept of entailment, namely, the concept of *multiple-conclusion entailment* or *mc-entailment* for short (cf. Shoesmith and Smiley, 1978). We say that a set of d-wffs X of $\mathscr{L}$ *multiple-conclusion entails* a set of d-wffs Y of $\mathscr{L}$ iff the following condition holds:

(#) *whenever all the d-wffs in X are true in some normal interpretation of $\mathscr{L}$, then there is at least one d-wff in Y which is true in this interpretation of $\mathscr{L}$.*

It is easily seen that X mc-entails the set $\{A\}$ just in case X entails (in the standard sense of the word) the d-wff A. On the other hand, the concept of mc-entailment is a non-trivial generalization of the concept of entailment: it happens that a set of d-wffs X mc-entails a set of d-wffs Y, but does not entail (in the standard sense) any d-wff in the set Y. The sets of the form $\{A \vee \neg A\}$ and $\{A, \neg A\}$, where A is an atomic sentence, give us a simple example here.

When we are dealing with questions, some concept of, to speak generally, "entailing a set of possibilities" is needed. Thus the application of the concept of mc-entailment in erotetic logic suggests itself. In fact, this concept proved its usefulness for the logic of questions in many ways. In particular, by means of the concept of mc-entailment we may define the concepts of generation and erotetic implication we are interested in.

(C) The definition of generation is an explication of the concept of the arising of a question from a set of declarative sentences. There is no room for presenting here the underlying intuitions in detail as well as the requirements of adequacy of the explication; they are presented in the paper Wiśniewski, 1989 (cf. also the book Wiśniewski 1990b, Chapter 1; or the paper Wiśniewski, 1991a for general intuitions). Roughly, the basic idea is that a question Q arises from a set of declarative sentences X just in case the truth of all the sentences in X guarantees the existence of a true direct answer to Q, but does not guarantee the truth of any particular direct answer to Q. In other words, Q arises from X just in case Q is made sound by X (isn't sound by its internal structure, but is sound assuming that X consists of truths), yet being at the same time also informative relative to X. The precise definition of generation is given by:

DEFINITION 1. A question Q is *generated* by a set of d-wffs X (in symbols: $\mathbf{G}(X, Q)$) iff

(i) the set of direct answers to Q is mc-entailed by the set X,
(ii) the set of direct answers to Q is not mc-entailed by the empty set, and
(iii) for each direct answer A to Q, the set $\{A\}$ is not mc-entailed by the set X.

The clause (i) of the proposed definition may be called the *relative soundness condition*; it is fulfilled iff Q is sound in each normal interpretation of $\mathscr{L}$ in which all the d-wffs in X are true. Thus *if* all the d-wffs in X are true (in some normal interpretation of the language; in what follows we will be normally omitting this provision, also with respect to soundness), then Q is sound, i.e. has some true direct answer(s). This is important, since by the clause (ii) Q is not sound by its internal structure (is risky). The conjunction of the first and second clauses explicates what it means that the truth of the formulas in X *guarantees* (provided that all d-wffs in X are true), sometimes to an unit class (it depends on the questions involved). On the other hand, clause (ii) yields that each direct answer to Q^* is potentially useful in that way. Let us recall here that the clause (i) guarantees that there must be some true direct answer to Q^* if Q is sound and X consists of truths! Let us also stress, however, that we neither assume nor deny here that Q is sound and that X consists of truths. But if X consists of truths, then either both the implied question and the implying question are sound, or neither of them is sound.

For the properties of erotetic implication and examples see the papers Wiśniewski, 1990a, 1991b, and 1994; cf. also the book Wiśniewski, 1990b, Chapter 6.

(E) We can now define the relevant concepts of question generating argument and question implying argument.

An e-argument of the first kind $\langle X, Q\rangle$ is a *question generating argument* iff the question Q is generated by the set of d-wffs X (i.e. $\mathbf{G}(X, Q)$ holds). An e-argument of the second kind $\langle Q, X, Q^*\rangle$ is a *question implying argument* iff the question Q^* is implied by the question Q on the basis of the set of d-wffs X (i.e. $\mathbf{Im}(Q, X, Q^*)$ holds).

(F) Let us now be more concrete. We shall describe some language $\mathscr{L}^*$ which may serve us as the language of logical analysis of erotetic argumentative steps involved in the presented train of thought.

The language $\mathscr{L}^*$ is an applied first order language enriched with expressions which enable us to form questions. For the sake of brevity we assume that the questions of $\mathscr{L}^*$ are either of the form (*) or of the form (**) (see above, Section 4(B)); thus the "erotetic" part of the vocabulary of $\mathscr{L}^*$ consists of the symbols ?, 1, /, |. The "declarative" part of the vocabulary contains a unary predicate $\mathbf{C}$, two dyadic predicates $\mathbf{F}$ and $\mathbf{U}$, one ternary predicate $\mathbf{S}$ and some further predicates, and also some individual constants and function symbols. (These expressions allow us int. al. to formulate the relevant meaning postulate(s) of the form MP-1). Terms and d-wffs of $\mathscr{L}^*$ are defined as usual; a *closed term* (a name) is a term with no individual variables. The sentential function $\mathbf{C}(x)$ is called the *category condition*. The grammar of $\mathscr{L}^*$ assigns to the category condition $\mathbf{C}(x)$ some fixed at least two element set of closed terms of $\mathscr{L}^*$; this set is called *the nominal category determined by the category condition* $\mathbf{C}(x)$ and will be referred to as $[\mathbf{C}(x)]$. We will use the letters α, β, τ as metalinguistic variables for closed terms of $\mathscr{L}^*$ and more specifically the letters $\gamma, \gamma_1, \ldots$ as metalinguistic variables for the elements of $[\mathbf{C}(x)]$. As mentioned above, *questions* of $\mathscr{L}^*$ have the forms:

(*) $\quad ?^1(\mathbf{C}(x)/A(x))$

where $A(x)$ is a sentential function with x as the only free variable,

(**) $\quad ?(A_1, \ldots, A_n \mid \neg A_1, \ldots, \neg A_n)$

where $n \geqslant 1$ and $A_1, \ldots, A_n$ are syntactically different sentences (d-wffs with no free variables). Let us recall that a *direct answer* to a question of the form (*) is a sentence of the form $A(\gamma_k)$, where γ_k belongs to $[\mathbf{C}(x)]$. A direct answer to a question of the form (**) is a sentence of the form:

(.) $\quad B_1 \,\&\, \ldots \,\&\, B_n$

where B_i – for $1 \leqslant i \leqslant n$ – is either of the form A_i or of the form $\neg A_i$.

The semantics of $\mathscr{L}^*$ is a model-theoretical semantics of the kind described above. This requires, however, that there are some *normal interpretations* of $\mathscr{L}^*$. The general idea underlying the definition is that in normal interpretations "having the property **C**" (where **C** is the predicate that occurs in the category condition $\mathbf{C}(x)$) and "being a value of some name from the nominal category determined by the category condition $\mathbf{C}(x)$" coincide. Thus, roughly, "being a goal" and "being a value of some goal-description" should coincide if the interpretation is to be normal, and similarly for the other cases. To be more precise, let us recall, first, that in extensional semantics the value of each closed term in a given interpretation is fixed and depends only on the interpretation function. Let us designate by $|\tau|^{\mathfrak{M}}$ the value of a closed term τ of $\mathscr{L}^*$ in the interpretation $\mathfrak{M}$ of $\mathscr{L}^*$. Normal interpretations of the language $\mathscr{L}^*$ can now be defined as follows:

DEFINITION 3. An interpretation $\mathfrak{M} = \langle M, f\rangle$ of $\mathscr{L}^*$ is a *normal interpretation* iff the following condition holds:

(!) $\quad f(\mathbf{C}) = \{y \in M\colon \text{for some } \tau \in [\mathbf{C}(x)],\ y = |\tau|^{\mathfrak{M}}\}.$

Thus an interpretation $\mathfrak{M} = \langle M, f\rangle$ is said to be normal just in case the interpretation function f assigns to the predicate **C** the set of all the elements the universe M of $\mathfrak{M}$ which are values in $\mathfrak{M}$ of the closed terms belonging to the nominal category determined by the category condition $\mathbf{C}(x)$.

We can now prove int. al. the following:[8,9]

THEOREM 1. $\mathbf{G}(\exists x(\mathbf{C}(x)\ \&\ H(x)),\ ?^1(\mathbf{C}(x))/H(x)))$, where $H(x)$ is an atomic d-wff of $\mathscr{L}^*$ with x as the only free variable.

Theorem 1 yields that

$$\frac{\exists x(\mathbf{C}(x)\ \&\ \mathbf{S}(\alpha, \beta, x))}{?^1(\mathbf{C}(x)/\mathbf{S}(\alpha, \beta, x))} \tag{1}$$

is a question generating argument and thus a valid e-argument. Recall that (1) occurs in Step 5 of the train of thought described above.

In what follows we will be using the letters A, B, ... as metalinguistic variables for d-wffs of $\mathscr{L}^*$; the expressions $A(x)$, $B(x)$, $A_1(x)$, ... will refer to d-wffs of $\mathscr{L}^*$ in which x occurs as the only free variable.

THEOREM 2: $\mathbf{Im}(?^1(\mathbf{C}(x)/A(x)), \{A(x) \equiv B\ \&\ A_1(x), B\}, ?^1(\mathbf{C}(x)/A_1(x)))$.

Theorem 2 yields that any e-argument of the form:

$$\frac{\begin{array}{l} ?^1(\mathbf{C}(x)/\mathbf{S}(\alpha, \beta, x)) \\ \mathbf{S}(\alpha, \beta, x) \equiv \mathbf{F}(\alpha, \beta)\ \&\ C_1(x)\ \&\ \ldots\ \&\ C_n(x) \\ \mathbf{F}(\alpha, \beta) \end{array}}{?^1(\mathbf{C}(x)/C_1(x)\ \&\ \ldots\ \&\ C_n(x))} \tag{2}$$

is a question implying argument and thus a valid erotetic argument. Recall that an e-argument of the form (2) occurs in Step 7.

THEOREM 3: $\mathbf{Im}(?^1(\mathbf{C}(x)/A_1(x)\ \&\ \ldots\ \&\ A_n(x)), \{\exists x(\mathbf{C}(x)\ \&\ A_1(x)\ \&\ \ldots\ \&\ A_n(x)), \mathbf{C}(\gamma_i)\}, ?(A_1(\gamma_i), \ldots, A_n(\gamma_i) \mid \neg A_1(\gamma_i), \ldots, \neg A_n(\gamma_i)))$, where γ_i is an element of $[\mathbf{C}(x)]$.

Theorem 3 yields, in turn, that any e-argument of the form:

$$\frac{\begin{array}{l} ?^1(\mathbf{C}(x)/C_1(x) \ \& \ldots \& \ C_n(x)) \\ \exists x(\mathbf{C}(x) \ \& \ C_1(x) \ \& \ldots \& \ C_n(x)) \\ \mathbf{C}(\gamma_i) \end{array}}{?(C_1(\gamma_i), \ldots, C_n(\gamma_i) \mid \neg C_1(\gamma_i), \ldots, \neg C_n(\gamma_i))} \tag{3}$$

where γ_i is an element of $[\mathbf{C}(x)]$, is a question implying argument and thus a valid e-argument. An e-argument of the form (3) occurrs in Step 9; such arguments can also occur in the analogous steps of other rounds (of course if there are any such rounds).

THEOREM 4: $\mathbf{Im}(?(A_1, \ldots, A_n \mid \neg A_1, \ldots, \neg A_n), ?(A_k \mid \neg A_k))$ for each $1 \leqslant k \leqslant n$,.

Thus each e-argument of the form:

$$\frac{?\ (C_1(\gamma_i), \ldots, C_n(\gamma_i) \mid \neg C_1(\gamma_i), \ldots, \neg C_n(\gamma_i))}{?(C_k(\gamma_i) \mid \neg C_k(\gamma_i))} \tag{4}$$

where $1 \leqslant k \leqslant n$, is a question implying argument and thus a valid e-argument. E-arguments of the form (4) occurr in Step 10; they may also occur in the analogous consecutive steps (if there are any).

Thus our general diagnosis is that each erotetic argument which occurs in the presented train of thought is a valid erotetic argument. On the other hand, each standard argumentative step involves only valid arguments as well. Hence, all argumentative steps in the train of thought described above are valid arguments, either standard or erotetic.

Let us add that the above diagnosis, although interesting itself, has also some interesting consequences. Let us notice, first, that if all the premises inserted on the non-argumentative steps preceding Step 5 are true, then our main explanation-seeking question (posed in Step 5) is sound, since it is generated by the premises. On the other hand, the question posed in Step 7 is implied by the main explanation-seeking question together with the factual statement and the meaning postulate MP-1. It follows that if our main explanation-seeking question is sound and the factual statement is true, then the question occurring in Step 7 is also sound (provided that the meaning postulate MP-1 is true). On the other hand, the remaining questions that occur in further steps are sound as well (they are safe questions). Thus we may conclude that *if* *all the declarative premises inserted in the non-argumentative steps of the train of thought described above are true, then also each question which occurs in it is sound, that is, has a true direct answer.*

(G) The present paper might give the impression of shooting with a sophisticated gun on a simple mouse. However, it will also be clear that the presented train of thought is such that a computer program can be written that guides the search for explanation by specification. Assuming that answers to the previous explanation-seeking questions will be stored, computer-assisted discovery and justification of explanation by specification may not only be possible but also useful. For instance, it might help biologists to look for functional explanation of newly discovered biological traits and insurance companies to look in an efficient way for causal explanation of accidents. For such computational applications a detailed description of the idealized thought process is of course required.

The computational perspective urges not only the question whether an alternative reconstruction of explanation by specification along the lines of Hintikka's interrogative approach to scientific inquiry (cf. e.g. the papers Hintikka, 1987, 1988, 1989) is possible, but also the question whether such a reconstruction is more, or less, suitable for computational implementation than the present reconstruction.

NOTES

[1] We follow here the idea of Belnap (cf. Belnap and Steel, 1976). Belnap admits also category conditions which are not atomic sentential functions.

[2] Note that the components for specific functional and causal statements include empirical laws. Hence, although explanation by specification greatly differs from explanation by nomological subsumption, it does not mean that laws cannot play an important role in it.

[3] Different which-questions are examined in detail in the book Belnap and Steel, 1976; questions of the form (*) are among the simplest. We use here the symbol / instead of the symbol // used by Belnap; we also disregard the distinction between questions and interrogatives.

[4] To be sure, in many cases it will be difficult to test the specific meaning components. But testing the CE-component (i.e. $C_n(\gamma)$ in the present case) is, as a rule, even more difficult. In practice, however, the testing of the CE-component is usually based on the following default rule (z stands here for an arbitrary element of $[C(x)]$):

CE-default: if the specific meaning components $C_i(z)$, for $i = 1, 2, \ldots, n-1$, hold and if there is no counter-information, then $C_n(z)$.

[5] In the previous publications of the first author it was suggested that in particular the

hidden application of existential generalization in Step 14a, resulting in the conclusion (3): $U(\alpha, \beta)$, is responsible for the generally shared feeling that explanation by specification involves valid argument. The present paper argues that this impression of validity can be justified for all argumentative steps.

[6] The basic idea of this definition was suggested by Bromberger (cf. Bromberger, 1992).

[7] Normal interpretations can be defined in different ways for different languages. For the definition of normal interpretations of the (concrete) language $\mathscr{L}^*$ of logical analysis of explanation by specification see Section 5 (F).

[8] For other theorems of this kind see the papers Wiśniewski, 1989, 1990a, and the book Wiśniewski, 1990b, Chapters 5 and 6.

[9] It is clear that theorems of this kind allow us to introduce the corresponding syntactic inferential rules (for this idea, see Wiśniewski, 1990b, Chapter 7).

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